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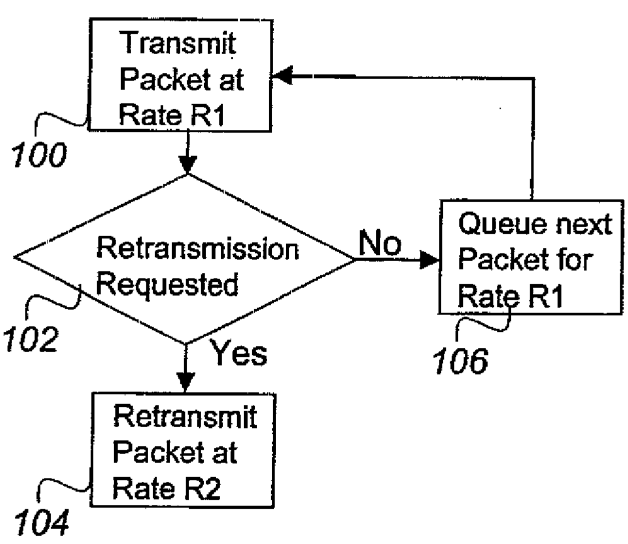
(54) **Title:** RETRANSMISSION METHOD AND APPARATUS FOR WIRELESS COMMUNICATIONS SYSTEMS



(57) **Abstract:** A wireless communications system method and apparatus transmits packet data at a first rate (R_1) selected to provide an acceptable packet error rate (PER) for a given wireless channel. Upon receipt of a request for retransmission of a data packet, the method and apparatus switch to a second rate (R_2), lower than the first rate, for retransmitting the data packet. The overall transmission rate becomes $R_1/(1+PER_1R_1/R_2)$, which is only slightly lower than that of the single rate retransmission $R_1/(1+PER_1)$, but the resulting $PER=PER_1PER_2$ is much smaller than PER_1^2 for the case of single rate retransmission.

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RETRANSMISSION METHOD AND APPARATUS FOR WIRELESS COMMUNICATIONS SYSTEMS

Field of the Invention

The present invention relates to a method of and apparatus for retransmission in wireless communications systems and is particularly concerned with packet retransmission.

Background of the Invention

The application of paradigms developed in wire line data transmission directly to wireless data transmission may lead to inefficient use of the limited bandwidth resources available in the wireless medium. One example of this is packet retransmissions. In wire line communications, such low error rates are available that packet retransmission involves relatively few packets and hence does not significantly impact throughput or result in unacceptable packet delays.

Summary of the Invention

An object of the present invention is to provide an improved method and apparatus for wireless communications systems packet retransmission.

In accordance with an aspect of the present invention there is provided a method of wireless data communications comprising the steps of: transmitting the data packet at a first rate; and upon receipt of a request to retransmit the data packet, transmitting the data packet at a second rate lower than the first rate.

Brief Description of the Drawings

Figs. 1a, 1b, 1c, 1d illustrate in block diagrams a wireless communications system;

Fig. 2 illustrates in a block diagram a wireless communications system with forward error detection (FED);

Fig. 3 illustrates in a block diagram a wireless communications system with forward error detection (FED) and retransmissions according to prior art;

Fig. 4 illustrates in a flow chart a method of wireless communication in accordance with an embodiment of the present invention; and

Fig. 5 illustrates in a block diagram a wireless communications system for implementing the method of Fig. 4.

Detailed Description of the Preferred Embodiment

Referring to Fig. 1a, there is illustrated a wireless communications system 10. For simplicity, the wireless communications system 10 includes two wireless stations (terminals) 12 and 14. Fig. 1b illustrates a wireless station of the wireless communications system 10 in further detail. The wireless station 12 (or 14) includes a data input 16 and a data output 18, a transmit path 20 and a receive path 30 and an antenna port 40.

Fig. 1c illustrates the transmit path of the wireless station of the wireless communications system 10 in further detail. The transmit path 20 typically includes a data randomization block 22, a forward error correction (FEC) coding block 24, a modulation block 26 and an RF conversion & amplification block 28. In operation, the typical transmit path 20 for a wireless communication system uses the data randomization block 22 to ensure that the modulated signal will have a uniform

spectrum. The FEC coding block 24 improves the communication robustness to noise or channel imperfections. Examples of FEC schemes are Reed-Solomon, convolutional or turbo coding. Depending on the FEC schemes this block may include one or more data interleaving schemes to improve the FEC performance. The modulation block 26 transforms data bits in base-band digital or analog signals Modulation schemes may (but they are not limited to) be single carrier or multi-carrier (e.g. OFDM) with different constellation mappings (e.g. BPSK, QPSK, QAM) and may include spectrum spreading techniques such as direct sequence spread-spectrum (DSSS) or frequency hopping (FH). The RF conversion and amplification block 28 includes but is not limited to all the necessary functional blocks to convert the signal from baseband to RF and amplify it to the desired transmission level.

Fig. 1d illustrates the receive path of the wireless station of the wireless communications system 10 in further detail. The receive path 30 typically includes an RF amplification conversion block 32, a FEC decoding block 34, a demodulation, equalizer & slicer block 36 and a data de-randomization block 38. These functions operate in reverse fashion to the corresponding blocks in the transmit section, with the exception of the equalizer which is necessary to compensate for the channel impulse response.

Most wireless communication systems can operate with several different combinations of coding and/or modulation Herein a combination of coding and modulation is referred to as a "rate", since the overall data rate (coding rate multiplied by the number of bits per symbol and by the symbol rate) describes the system outcome.

Typically, wireless communication systems can automatically change the "rate" with which they operate in order to compensate for changes in the channel, i.e. attenuation, multipath, natural noise and interference, changes in channel are perceived by the wireless system as changes in the overall signal-to-noise-ratio (SNR). For a given SNR, there is a tradeoff between data rate and the link bit-error-rate (BER) or packet-error-rate (PER). The higher the date rate, the higher the error probability. Wireless communication systems that are capable of adapting their "rate"

to the channel characteristics, set their "rate" enough low such that the overall BER or PER falls within quality requirements for the link. Typical requirements for overall BER are in the order 10^{-4} to 10^{-12} depending on the application.

In a wireless communication system with no retransmission, each data packet is sent only once. If transmission encountered errors (detected either at the level of the wireless system or at a higher level in the protocol) the corresponding data is discarded or, in other words, is lost. For such systems, the "rate" is set enough low so that the BER/PER meets the quality requirements for the link. Such a strong condition on BER/PER leads to poor usage of the wireless channel since the "rate" is significantly reduced below the potential rate (by 20% to 50%) to meet 10^{-4} to 10^{-12} BER/PER requirements.

Referring to Fig. 2 there is illustrated another form of wireless station of the wireless communications system 10 in further detail. In addition to the functional blocks shown in Fig. 1b, Fig. 2 includes a forward error detection (FED) function 50 that includes a FED add block 52, a FED check block 54 and a data valid/invalid output 56. Many wireless systems monitor the BER/PER to ensure proper operation. This is usually performed using error-detection techniques. At transmission the FED redundant information is appended or inserted in the data stream by the FED add block 52. At reception the FED information is extracted from the data stream by the FED check block 54 and used to verify if the received data is valid or not. Invalid data packets are eventually removed from the received data stream.

Typical forward-error-detection (FED) techniques add some redundancy at transmission, like parity check bits or cyclic-redundant-codes (CRC) that can be verified at reception, in order to validate/invalidate packets. Alternatively, error detection may be combined with error correction like with Reed-Solomon FEC/FED or other error detecting and correcting cods. Without any loss of generality, the presentation discusses the case of separate FEC and FED.

In some wireless systems, results of the error detection are exchanged between terminals systems in the form of acknowledge (ACK) and not-acknowledge (NACK) messages. This is to enable the sender of the packet to know if the packet was received properly. For simplicity and clarity, the present application refers only to packet-by-packet ACK/NACK messages but embodiments of the present invention can be applied to systems that employ group or multi-packet ACK/NACK

Often, systems that implement both FED and ACK/NACK, also employ packet retransmission. In communication system with retransmission, the sender of a packet stores data until an ACK or a NACK is received for that packet or, in other words, until it knows if the packet was or was not properly transmitted to the receiver. If the sender receives ACK, it proceeds with the next packet. If the sender receives NACK, it tries to retransmit the stored packet. Depending of the system, one or more retransmissions may be allowed. Again, for the simplicity the document refers only to packet-by-packet retransmissions but the invention can be applied to group selective or group non-selective retransmissions like "selective-repeat", "go-back-N" or others.

Referring to Fig. 3 there is illustrated a further form of wireless station of the wireless communications system 10 in further detail. In addition to the functional blocks shown in Fig. 2, Fig. 3 includes an ACK/NACK Extractor 60 coupled to the output of the Rx path 30 and an ACK/NACK Generator 62 coupled to the input of the Tx path 20. Fig. 3 also includes a transmit data buffer 64 and a switch 66. The ACK/NACK extractor 60 is coupled to the switch.

In operation, each packet sent is buffered in the transmit data buffer 64. When a packet is not acknowledged either by not receiving an ACK within a specified time or receiving a NACK, the ACK/NACK Extractor causes the switch 66 to switch from a transmit position to a retransmit position to cause the missing packet to be resent. Similarly, the ACK/NACK generator 62, based on output from the FED check block 54 appends the appropriate ACK or NACK to transmitted packets.

In a wireless communication system with retransmission, the transmitted data is grouped in packets (also called frames, bursts, etc) and the receiving station acknowledges each received data packet (implicitly or explicitly) to the transmitting station. The transmitting station can then retransmit the erroneous packets Retransmission improves exponentially the overall BER/PER for the same channel with a little decrease in the overall data rate. If PER_1 and R_1 are the PER and, respectively, the "rate" without retransmission then if n retransmissions are allowed and the channel characteristics are constant, the overall PER with retransmissions is $PER_0=PER_1^{n+1}$ and the overall rate is $R_0=R_1(1-PER_1)/(1-PER_1^{n+1})$. The loss in rate between R_1 and R_0 is very small (less then PER) but the improvement from PER_1 to PER_0 is significant. For example allowing up to 3 retransmissions improves the BER/PER from 10^{-4} to 10^{-16} and from 10^{-2} to 10^{-8}. Therefore, wireless systems with retransmission can operate with higher PER_1 which in terms means increased "rate". The rate back off in wireless systems with retransmission can theoretically be much smaller (e g 5-10%) that in systems without retransmission. The increase in rate facilitated by retransmission is much higher that the difference between R0 and R1, and thus systems with retransmission utilize more efficiently the channel.

However, systems with retransmissions still have several drawbacks. The more retransmissions are allowed the higher the potential packet delay is. One retransmission is often not enough to improve the BER to the desired level with a rate back off of less than 20%.

The improvement in systems with retransmission from PER_1 to $PER_0=PER_1^{n+1}$ takes place only if the channel does not change. However, wireless channels are generally not constant. Path loss varies slowly at least with the environment changes (temperature, humidity, clouds, rain/snow, seasons) but can vary quickly in mobile and/or multi-path environments. In unlicensed bands, the interference level can show rapid changes, for example, transmission bursts from interfering station. Rapid changes in SNR cannot be tracked by the adaptation algorithm typically used to establish the "rate" in variable rate systems. Therefore, with or without retransmissions there might be periods when no packet can be correctly transmitted

unless the rate is a priori backed off enough to cover the minimum SNR case During such periods, the communications link is effectively lost and packets accumulate at both stations until either the channel returns to normal or the "rate" adaptation algorithm reacts. This further increases the packet delay to a degree, which in many cases, may be unacceptable (i.e. the accumulated packets must be discarded and thus they are lost).

Due to delay and adaptation issues discussed above, more than one retransmission is rarely used in practice. Also, in many practical situations, systems with retransmission are used with similar "rate" back-off as those without retransmission.

Referring to Fig. 4, there is illustrated, in a flow chart a method of packet transmission for a wireless communications system, in accordance with an embodiment of the present invention. The method includes a step of initially transmitting a data packet at a first rate, R_1 and represented by a block 100. The first rate R_1 being a rate, chosen to provide a predetermined level of packet error-ratio (PER). If a request for retransmission is received, as represented by a decision block 102, then resending the packet at a second rate, R_2, which is lower than the first rate R_1 Otherwise, transmitting the next packet.

The retransmission method of Fig. 4 limits the number of retransmissions to one but retransmissions are performed with a lower "rate" ($R_2<R_1$). If the channel is constant and the PER for rate R_2 is PER_2, then the overall PER of a system using the retransmission method of Fig. 4 is: $PER_0=PER_1PER_2$ and the overall data rate is: $R_0=R_1/(1+PER_1R_1/R_2)$.

When compared with a typical system with one retransmission, the system with dual-rate retransmission it has slightly lower overall rate, i.e. $R_1/(1+PER_1R_1/R_2)$ instead of $R_1/(1+PER_1)$, however this is more than offset by a much better PER, i.e. $PER_1PER_2<<PER_1^2$. This occurs because PER_2/PER_1 is typically 10^{-4} to 10^{-8} for a

20% decrease in rate. Therefore the system using the retransmission method of Fig. 4 has overall BER and rate characteristics that are similar to systems with multiple retransmissions in constant channels.

Referring to Fig. 5, there is illustrated a wireless communications station incorporating the method of Fig. 4. The wireless communications station of Fig. 5 is similar to that of Fig. 3, except the data buffer 64' provides data for retransmission at a second rate R_2 that is lower that the transmission rate R_1. This accomplished by connection 68 that takes the output of the ACK/NACK Extractor 60 and passes as control input to the Tx Path 20 for the purpose of switching between rates R_1 and R_2.

With a proper choice of R_2 and consequently of BER_2, the system with dual-rate transmission can achieve BER and rate characteristics of a system with n retransmissions while maintaining a maximum delay similar to that of a system that allows only one retransmission at the same rate as the initial transmission.

In variable channels, the second rate R_2 can be further reduced so that it provides an acceptable overall BER for the worst case. Thus, with a very small decrease in the overall average rate, the dual rate system of Figs. 4 and 5 can automatically avoid extreme packet loss and/or packet delays during accidental (rare) SNR drops without any intervention from a "rate" adaptation algorithm. When compared to standard retransmission, the dual-rate system gains link margin via R_2 instead of R_1, thus it can insure higher immunity to channel variations at very little expense in the overall rate.

A wireless system using the dual-rate retransmission algorithm of Fig. 4 has the advantage of providing performance similar to multiple retransmission algorithms, while incurring a delay similar to that of single-retransmission algorithms

A further advantage to the dual-rate retransmission algorithm of Fig. 4 is that it can operate with very little back-off for R_1 and very large back-off for R_2. Thus it optimizes the overall rate while it optimizes the immunity to channel variations.

Some implementations may measure PER over a predetermined number of packets or a combination of both.

Numerous modifications, variations and adaptations may be made to the particular embodiments of the invention described above without departing from the scope of the claims, which is defined in the claims.

What is claimed is:

1. A method of wireless data communications comprising the steps of:

   a) transmitting a data packet at a first rate;

   b) upon receipt of a request to retransmit the data packet, retransmitting the data packet at a second rate lower than the first rate.

2. A method as claimed in Claim 1 wherein the first rate is selected in dependence upon an average packet error rate (PER) as determined for packets sent at the first rate and the second rate is selected in dependence of the average PER to achieve a desired overall PER/BER, whereby the first rate is selected to maximize the data throughput and the second rate is selected

3. A method as claimed in Claim 1 wherein the first rate is selected in dependence upon an average packet error rate (PER) as determined for packets sent at the first rate and the second rate is selected in dependence upon the peak PER measured for the packets send with the first rate to achieve a desired overall PER/BER, whereby the first rate is selected to maximize the data throughput.

4 A method as claimed in Claim 1 wherein the first rate is selected in dependence upon an average packet error rate (PER) determined for packets sent at the first rate and the second rate is selected in dependence upon an average PER measured for the packets sent at the second rate to achieve a desired overall PER/BER, whereby the first rate is selected to maximize the data throughput.

5 A method as claimed in Claim 1 wherein the first rate is selected in dependence upon an average packet error rate (PER) determined for packets sent at the first rate so as to maximize the data throughput and the second rate is selected in

dependence upon the average PER determined for packets sent at the second rate to achieve the desired overall PER/BER.

6. A method as claimed in Claim 1 wherein the first rate is selected in dependence upon an average packet error rate (PER) determined for packets sent at the first rate so as to maximize the data throughput and the second rate is selected in dependence upon a peak PER determined for the packets sent at the second rate so as to obtain the desired overall PER/BER.

7. A method as claimed in Claim 6 wherein the request to retransmit the data packet is a not-acknowledge message.

8 A method as claimed in Claim 6 wherein the request to retransmit the data packet is a result of not receiving an acknowledge message.

9. A method as claimed in Claim 7 wherein the request to retransmit is generated a predetermined time after transmitting the data packet.

10. A method as claimed in Claim 8 wherein the request to retransmit is generated a predetermined time after transmitting the data packet.

11. Apparatus for wireless data communications comprising the steps of:

c) transmitting a data packet at a first rate;

d) upon receipt of a request to retransmit the data packet, retransmitting the data packet at a second rate lower than the first rate

12. Apparatus as claimed in Claim 11 wherein the first rate is selected in dependence upon an average packet error rate (PER) as determined for packets sent at the first rate and the second rate is selected in dependence of the average PER to achieve a desired overall PER/BER, whereby the first rate is selected to maximize the data throughput and the second rate is selected.

13. Apparatus as claimed in Claim 11 wherein the first rate is selected in dependence upon an average packet error rate (PER) as determined for packets sent at the first rate and the second rate is selected in dependence upon the peak PER measured for the packets send with the first rate to achieve a desired overall PER/BER, whereby the first rate is selected to maximize the data throughput.

14. Apparatus as claimed in Claim 11 wherein the first rate is selected in dependence upon an average packet error rate (PER) determined for packets sent at the first rate and the second rate is selected in dependence upon an average PER measured for the packets sent at the second rate to achieve a desired overall PER/BER, whereby the first rate is selected to maximize the data throughput.

15. Apparatus as claimed in Claim 11 wherein the first rate is selected in dependence upon an average packet error rate (PER) determined for packets sent at the first rate so as to maximize the data throughput and the second rate is selected in dependence upon the average PER determined for packets sent at the second rate to achieve the desired overall PER/BER.

16. Apparatus as claimed in Claim 11 wherein the first rate is selected in dependence upon an average packet error rate (PER) determined for packets sent at the first rate so as to maximize the data throughput and the second rate is selected in dependence upon a peak PER determined for the packets sent at the second rate so as to obtain the desired overall PER/BER.

17. Apparatus as claimed in Claim 16 wherein the request to retransmit the data packet is a not-acknowledge message.

18 Apparatus as claimed in Claim 16 wherein the request to retransmit the data packet is a result of not receiving an acknowledge message.

19. Apparatus as claimed in Claim 17 wherein the request to retransmit is generated a predetermined time after transmitting the data packet.

20. Apparatus as claimed in Claim 18 wherein the request to retransmit is generated a predetermined time after transmitting the data packet.

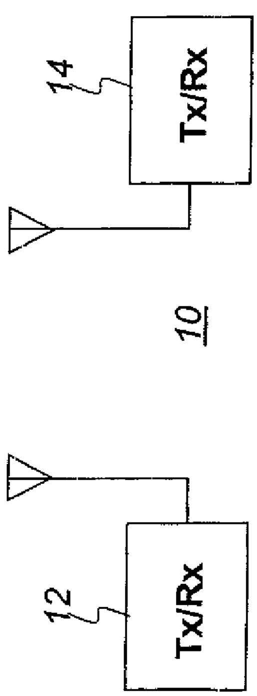


Fig. 1a

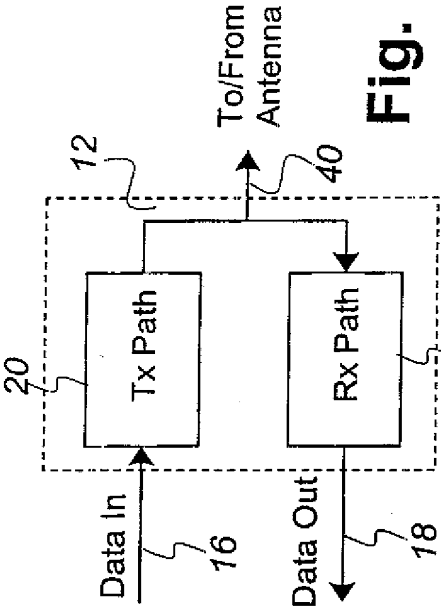


Fig. 1b

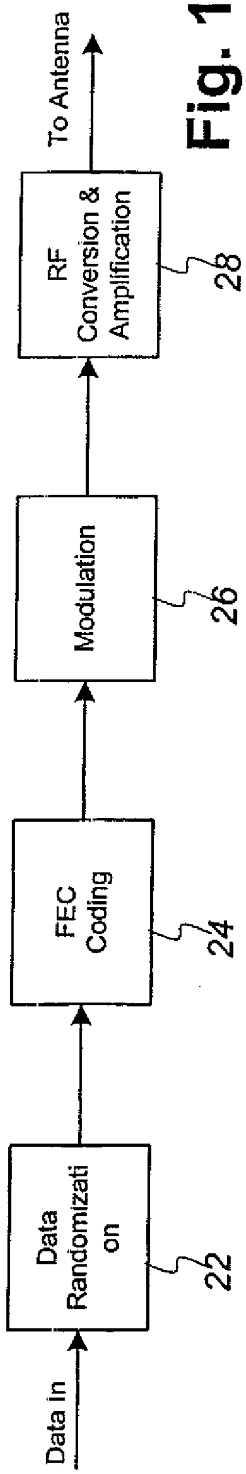


Fig. 1c

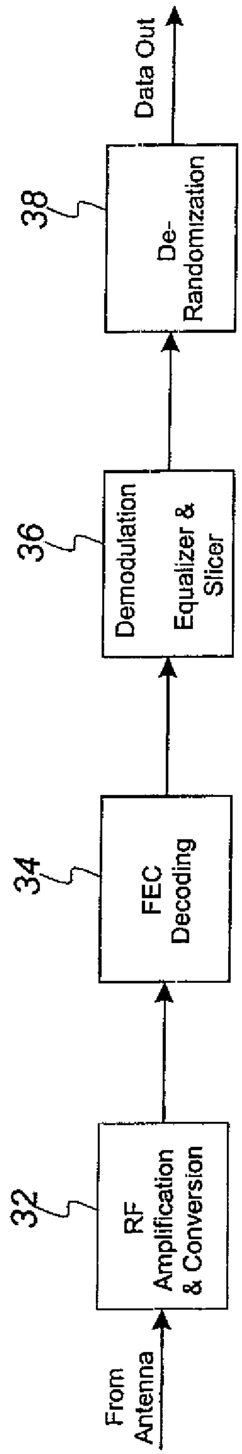


Fig. 1d

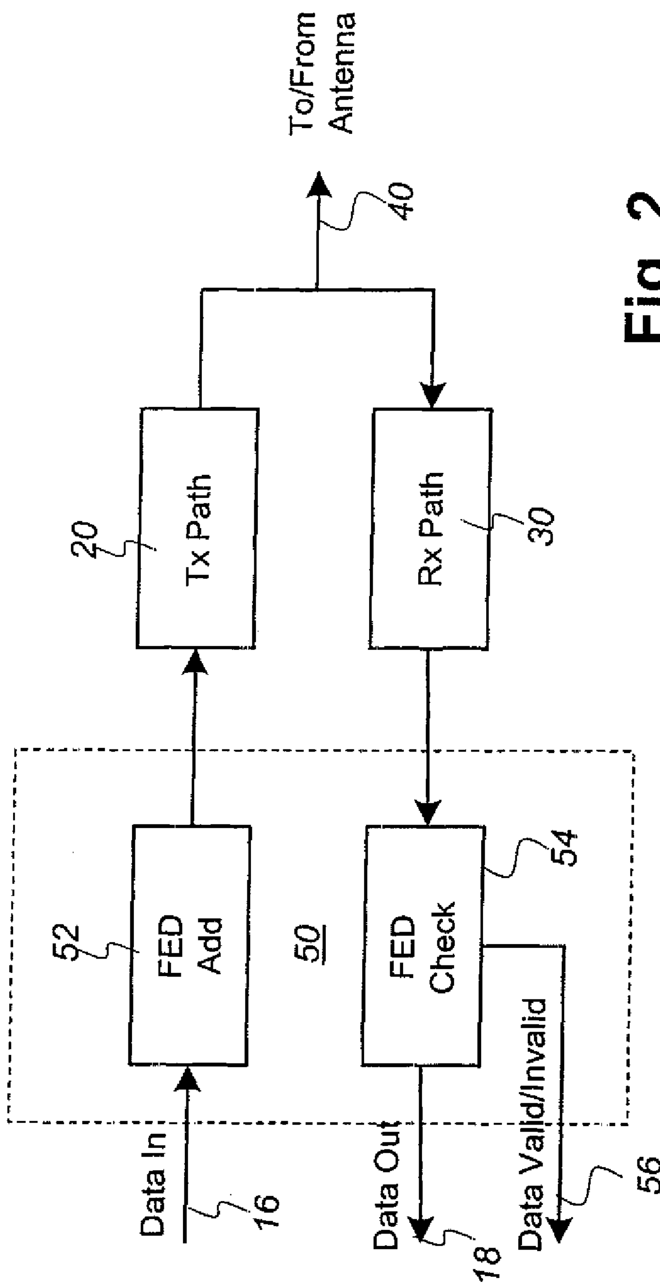
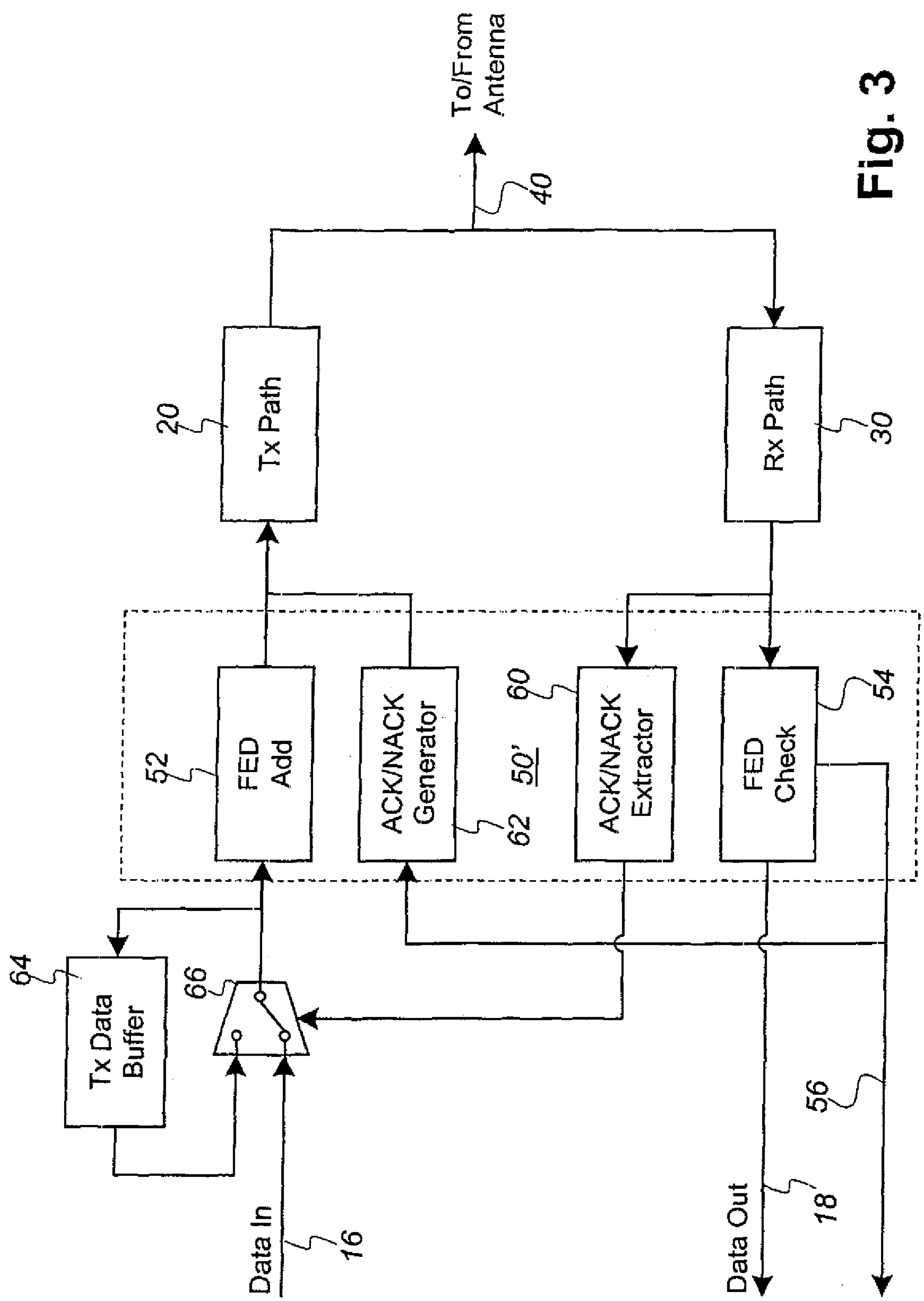

To/From Antenna
40
Tx Path
20
Rx Path
30
FED Add
52
50
FED Check
54
Data In
16
Data Out
18
Data Valid/Invalid
56

Fig. 2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Rx Path
30
52
FED Add
ACK/NACK Generator
62
50'
60
ACK/NACK Extractor
FED Check
54
64
Tx Data Buffer
66
Data In
16
Data Out
18
56

Fig. 3

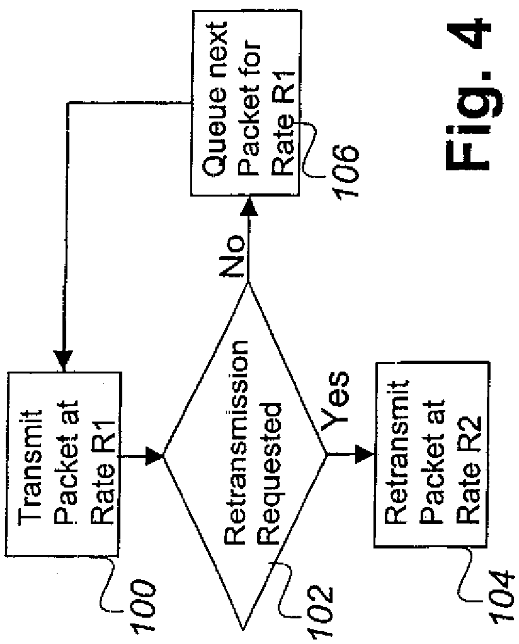
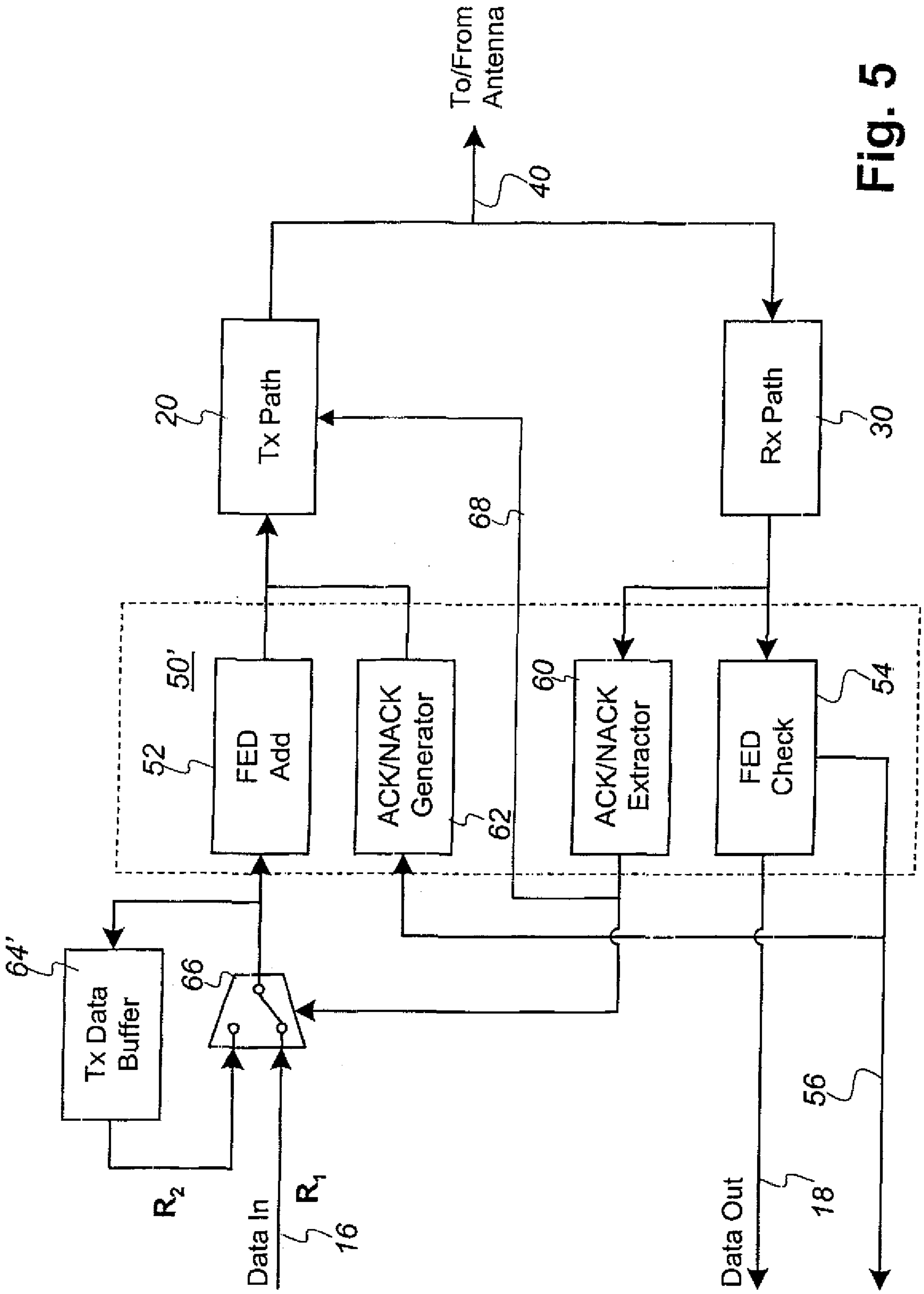

Transmit Packet at Rate R1
100
Retransmission Requested
102
No
Queue next Packet for Rate R1
106
Yes
Retransmit Packet at Rate R2
104

Fig. 4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30
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ACK/NACK Generator
62
60
ACK/NACK Extractor
FED Check
54
64'
Tx Data Buffer
66
56
R2
R1
Data In
16
Data Out
18

Fig. 5

INTERNATIONAL SEARCH REPORT

International Application No
PCT/CA 02/01252

A. CLASSIFICATION OF SUBJECT MATTER
IPC 7 H04L1/00 H04L1/18

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
IPC 7 H04L

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

EPO-Internal, INSPEC, COMPENDEX

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category °	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	WO 00 21236 A (ERICSSON TELEFON AB L M) 13 April 2000 (2000-04-13) abstract page 4, line 28 -page 5, line 27 page 9, line 15 -page 11, line 25	1-20
X	WO 01 54339 A (NORTEL NETWORKS LTD ;ROYER CLAUDE (CA); TONG WEN (CA); PERIYALWAR) 26 July 2001 (2001-07-26) abstract figure 2 page 8, line 17 -page 9, line 19 page 12, line 25-34	1-20

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[X] Further documents are listed in the continuation of box C.

[X] Patent family members are listed in annex.

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"O" document referring to an oral disclosure, use, exhibition or other means

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"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
10 January 2003	17/01/2003

Name and mailing address of the ISA	Authorized officer
European Patent Office, P.B. 5818 Patentlaan 2 NL - 2280 HV Rijswijk Tel. (+31-70) 340-2040, Tx. 31 651 epo nl, Fax: (+31-70) 340-3016	Borges, P

Int ional Application No
PCT/CA 02/01252

C.(Continuation) DOCUMENTS CONSIDERED TO BE RELEVANT

Category °	Citation of document, with indication where appropriate of the relevant passages	Relevant to claim No
X	WO 00 49760 A (ERICSSON TELEFON AB L M) 24 August 2000 (2000-08-24) figure 7 page 6, line 1 - line 9 page 7, line 26 - line 30 page 13, line 10 -page 14, line 6 -----	1-20

INTERNATIONAL SEARCH REPORT

Information on patent family members

Int ional Application No
PCT/CA 02/01252

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